Laboratory Evaporation and Desorption Instrumentation Systems (Wind Tunnels) for Measuring the Environmental Fate of Toxic Chemicals: Comparison of Velocity Profiles with the Earth Surface Layer Profiles

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Outline

- **Atmospheric Simulation**
- **ECBC Agent Fate Wind Tunnels**
  - Microbalance Wind Tunnels
  - Vapor Sample Wind Tunnels, Single Droplet, 5x5-cm Wind Tunnel
- **Comparison of Earth's Surface Layer Velocity Profile to Wind Tunnel Profiles**

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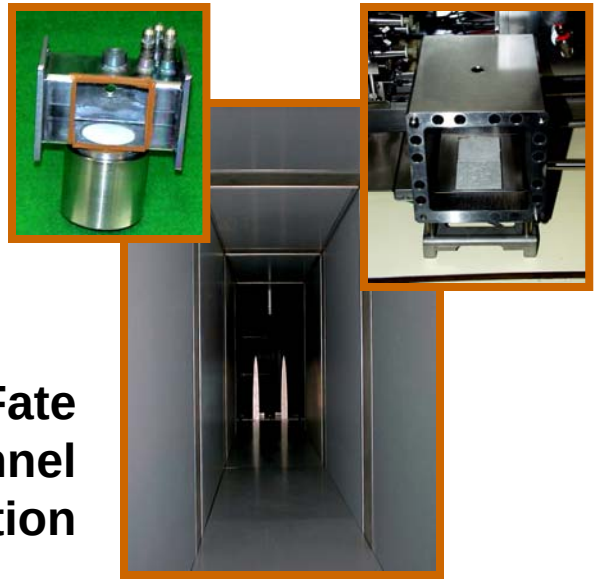
Shrinking Down the Atmosphere

Lab Chemical Fume Hood



Agent Fate Wind Tunnel Test Section

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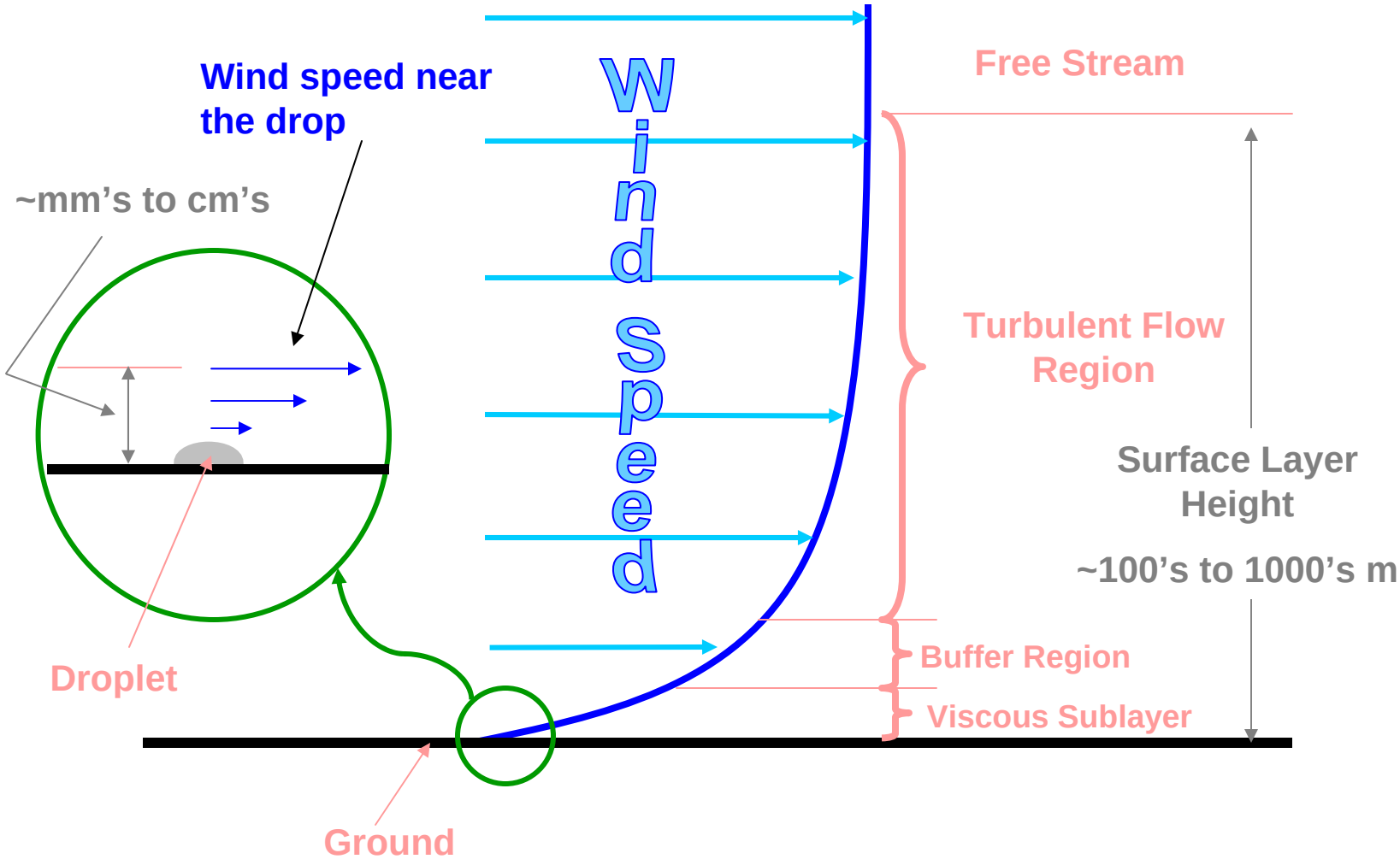
Atmospheric Surface Layer



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Theoretical Vertical Profiles of the Earth's Surface Layer

- **Typically described by Frost Curves or a form of the "Law of the Wall"**
- **Frost Curves or Power-Law Form of the**

$$\frac{U}{U_o} = \left(\frac{z}{z_o}\right)^p$$

Where U_o and z_o is the reference altitude and corresponding wind speed. P denotes level of atmospheric mixing

- **"Law of the Wall"**

$$\frac{u}{u^*} = (u^*)\frac{z}{\nu}$$

Laminar sublayer equation where u* is the friction velocity, and nu is the air's kinematic viscosity.

$$\frac{u}{u^*} = \left(\frac{1}{\kappa}\right)\ln\left((u^*)\frac{z}{\nu}\right) + B$$

Turbulent region equation where κ is the Von-Karman constant usually = 0.4 and B is a constant ~ 5.5.

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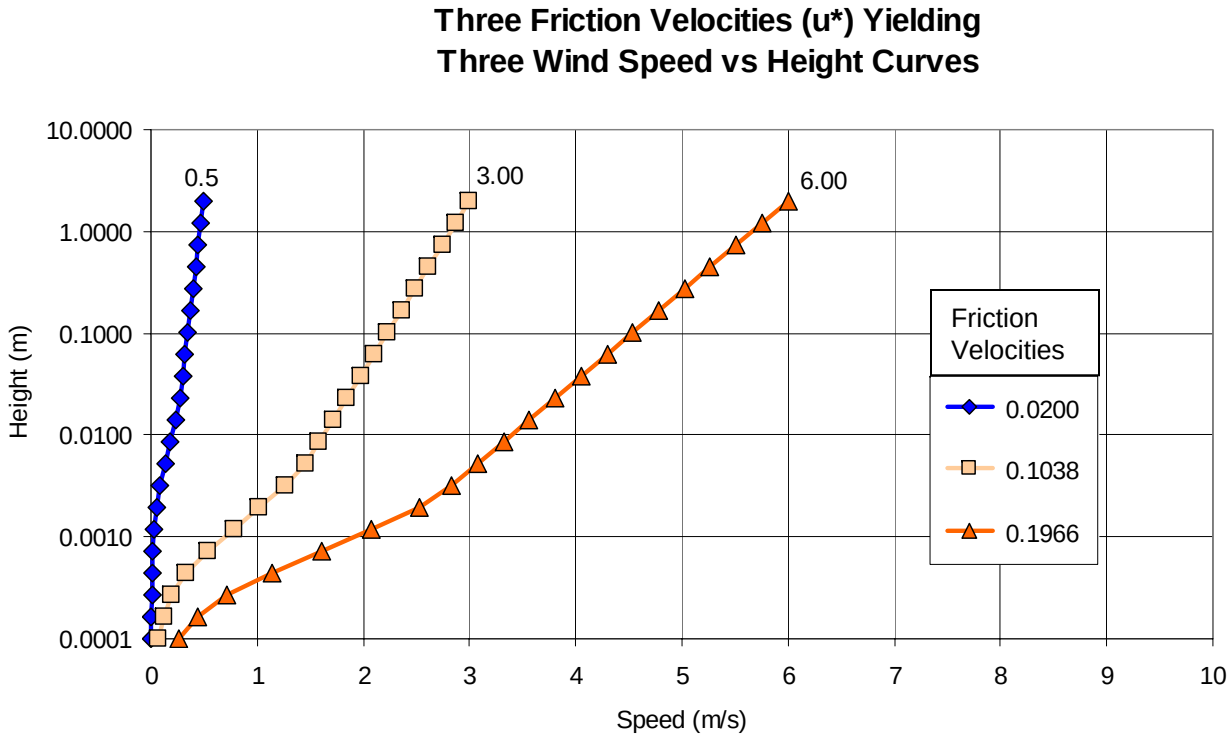
Theoretical Surface Layer Approximations

- **Boundary-Layer approximations extended from 2m to near surface**
- **Based on selection of friction velocities to match empirical atmospheric velocities at 2m: 0.5, 3.0 and 6.0 m/s**



Target Velocity Design Specifications

Estimation of 2m Velocities For Two Q600 Flow Rates

		Flow Rates (ml/min)		
		100	1000	
Friction Velocities, u*		0.007	0.02	
Heights (mm)	1	0.0033	0.03	Velocities (m/s)
	2000	0.154	0.5	

Estimated from CFD

Adjusted u* value in to match the 1mm velocity . Then estimated 2m velocity

1000ml/min CFD estimates matched the 0.5m/s at 2m height profiles

TGA 2950 and 5x5 cm Wind Tunnel Target Velocities			
Height (mm)	**Low (m/s)**	**Med (m/s)**	**High (m/s)**
1	**0.003**	**0.678**	**1.882**
10	**0.222**	**1.58**	**3.308**
2000	**0.5**	**3.0**	**6.0**

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ECBC Agent Fate Wind Tunnels

- **Microbalance (Thermo-gravimetric Analyzers (TGA))**
  - Single sample pan (model 2950)
  - Dual sample pan (model Q600)
- **Single and Multiple Drop Vapor Sampled**
  - 5x5-cm test section

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ECBC Wind Tunnel Facilities

- **Single drop**
- **Velocity: low, medium and high**
- **Temperature range: 25 to 45 °C currently, 0 to 55 being installed**
- **Humidity range: ~15 to 60% RH**
- **Primary analysis technique**
  - Microbalance: gravimetric
  - 5x5-cm wind tunnel: vapor analysis
- **Additional analyses techniques**
  - Droplet optical imaging
  - Extraction and in situ NMR (Nuclear Magnetic Resonance) analysis
  - HS-SPME (Head Space - Solid Phase Micro-extraction)
  - Others

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Microbalance Wind Tunnels

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Microbalance Wind Tunnels Based on Thermal Gravimetric Analyzers (TGA)

- **TGA's features**
  - Extremely sensitive mass balance ~ 0.1 microgram
  - Temperature control
  - Low air flow rates
  - Record evaporation and desorption of liquid as a function of time
- **Convert TGA to a small wind tunnel by:**
  - Characterize flow field above sample pans
  - Determine flow rate upper limit on TGA measurement sensitivity.

Model Q600 TGA

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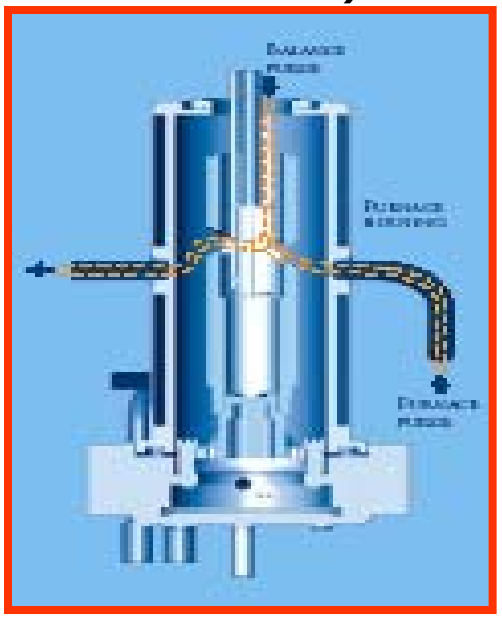
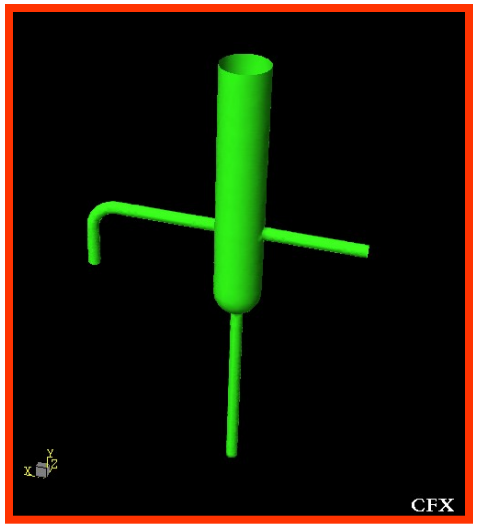
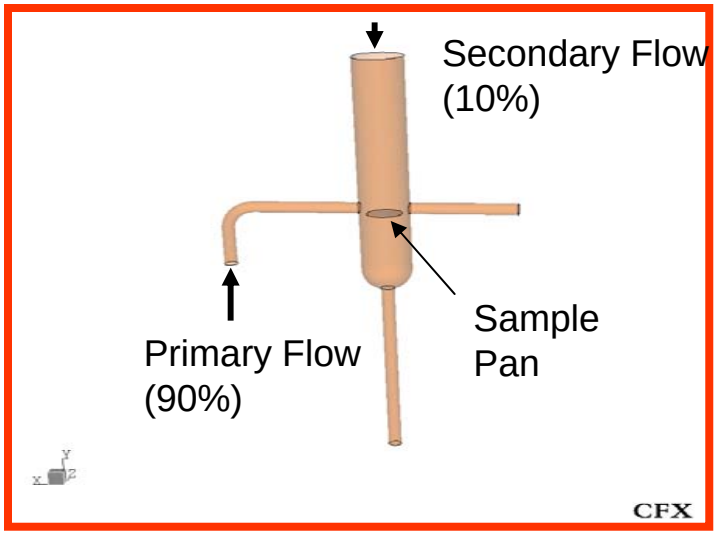
Lab Microbalance Wind Tunnel (TA Instruments Model 2950)

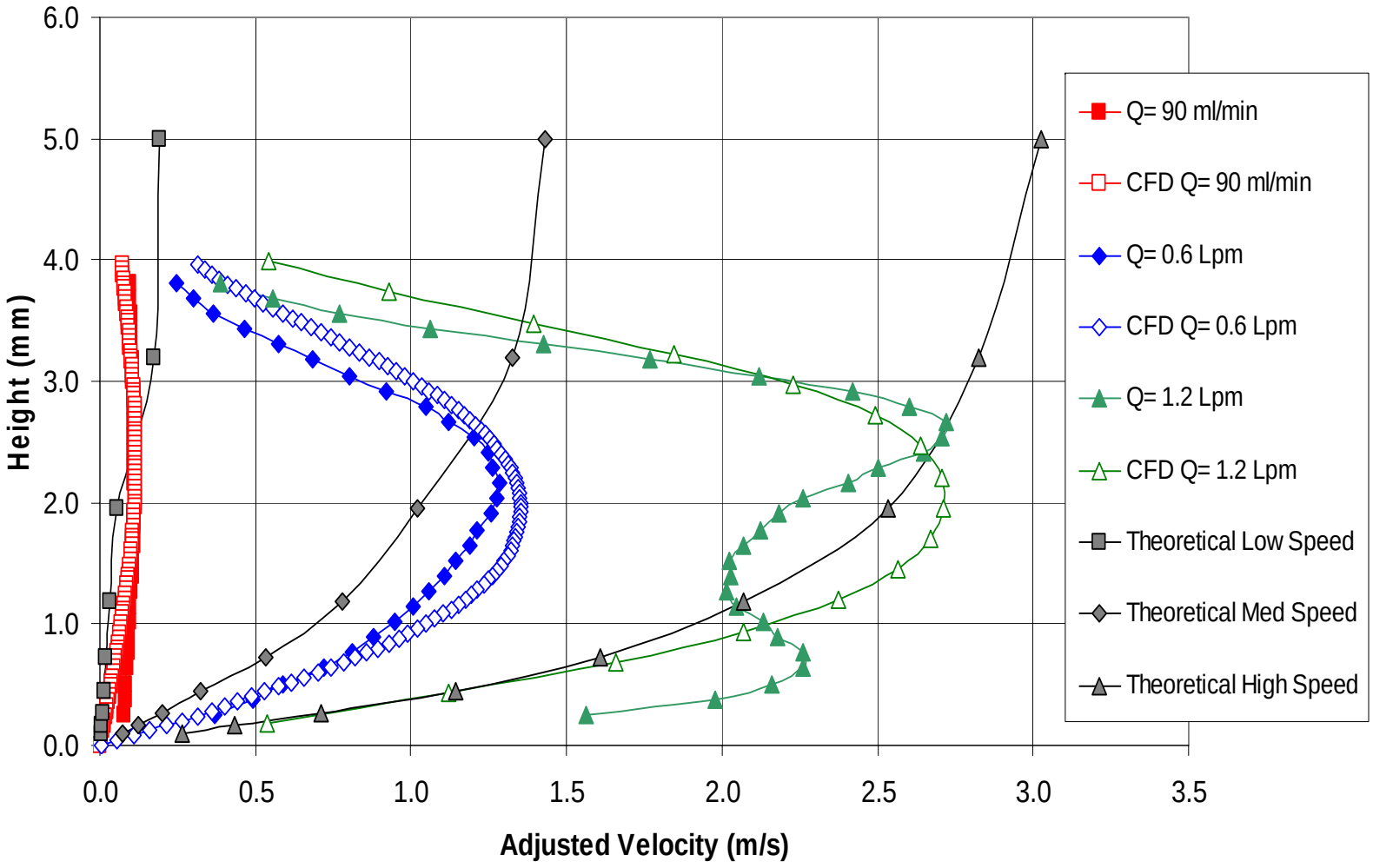
- **Experimental profiles measured in the quartz tube above sample pan**
- **Three flow rates: 0.09, 0.6 and 1.2 Lpm**
  - Measured profiles: no secondary flow
  - Simulated profiles with CFD: above flow rates represent primary flows with 10% secondary flows across entire large tube diameter.
- **Model with and without sample pan**







TA Instruments Model 2950 Velocity Profiles



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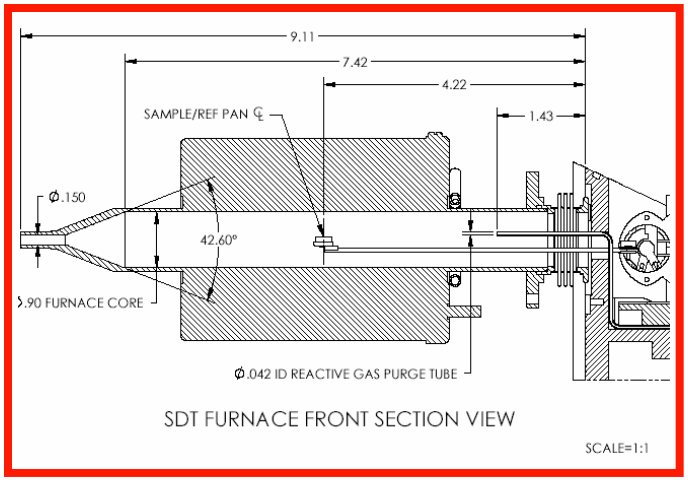
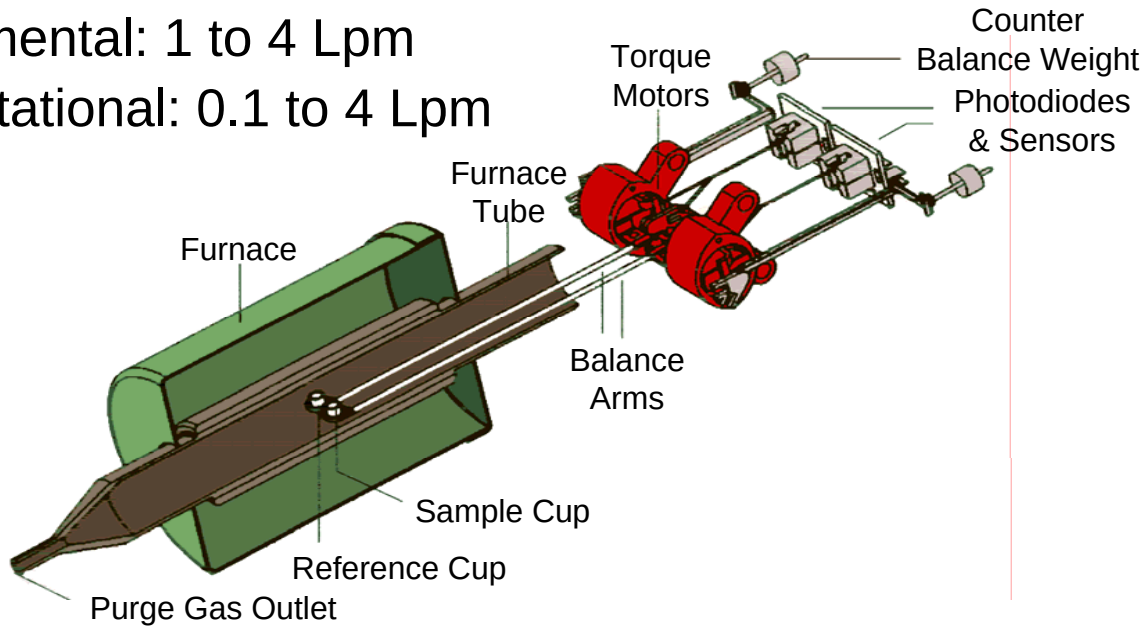
Lab Microbalance Wind Tunnel (TA Instruments Model Q600)

- **Simplify geometry for experimental study**
  - Excluded balance section
- **Simplify geometry for CFD**
  - Excluded balance section
  - Excluded balance rods
- **Range of flow rates**
  - Experimental: 1 to 4 Lpm
  - Computational: 0.1 to 4 Lpm





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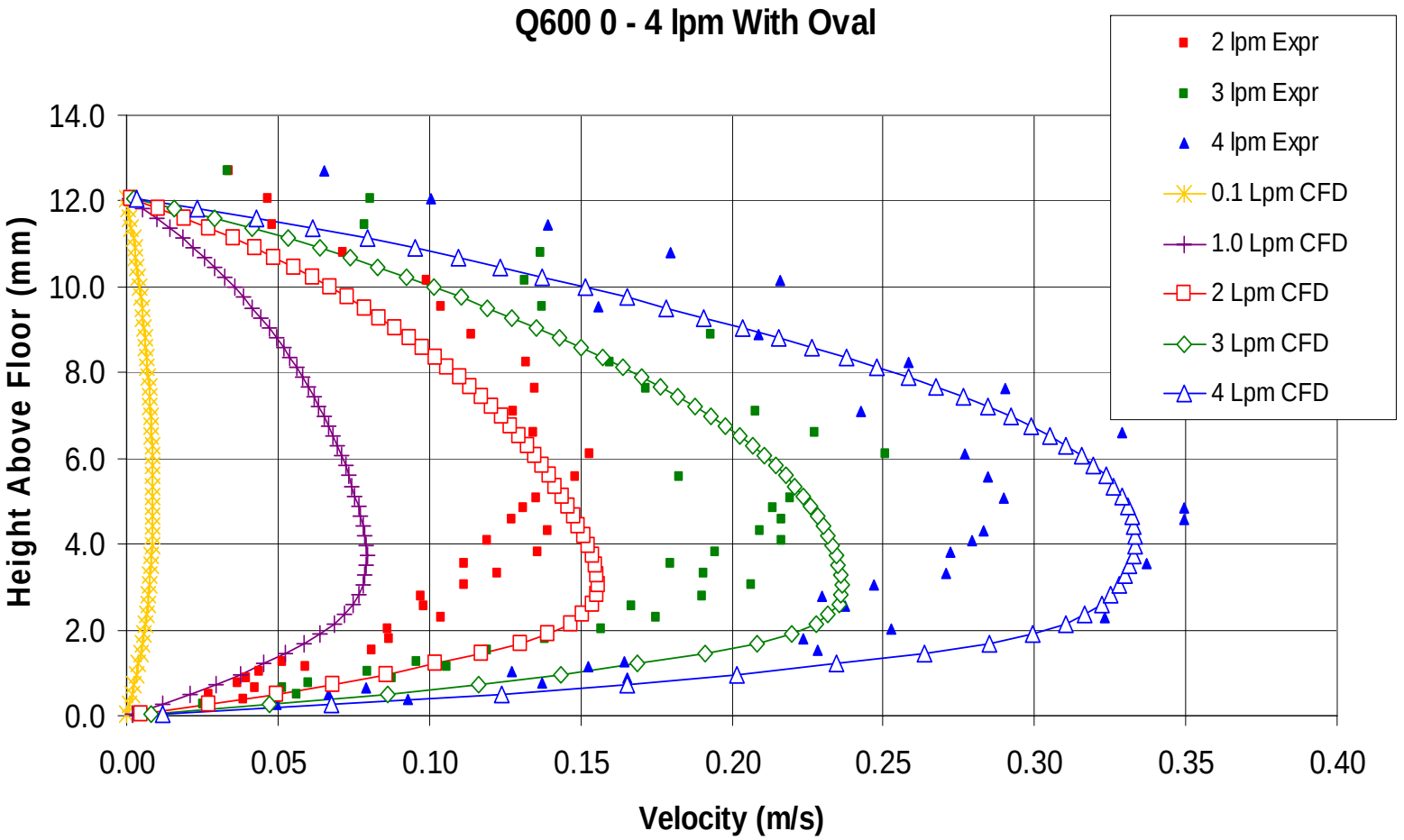
TA Instruments Model Q600 Velocity Profiles



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Single Droplet, Vapor Sampled, 5x5-cm Wind Tunnel

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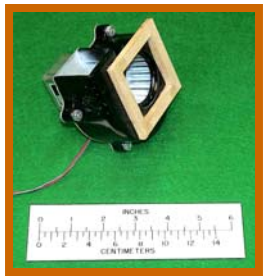
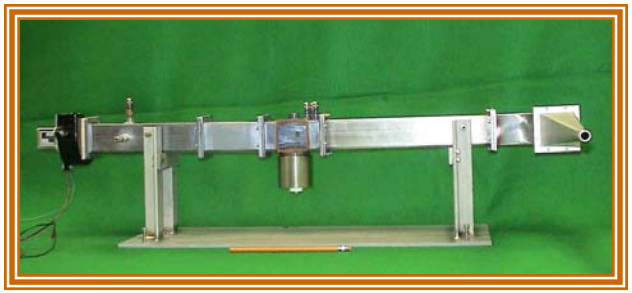
5x5-cm Wind Tunnel Sections



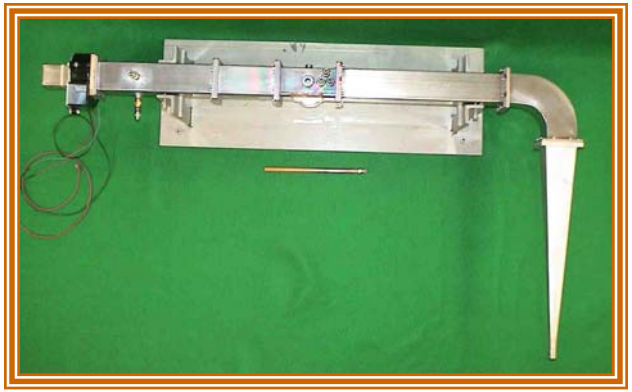
Blower



Front View

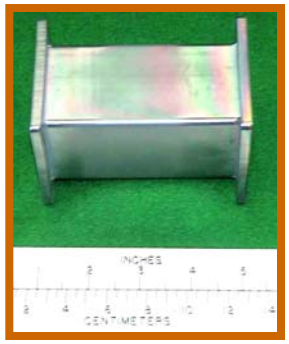
Miller Nelson Transition

Sampling



Top View

Turning



Static Mixer

Test Section

Fetch

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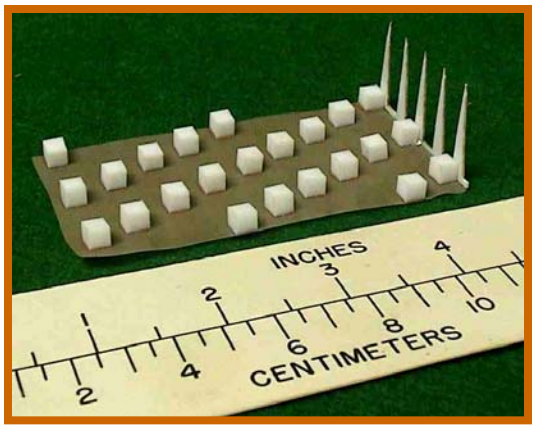
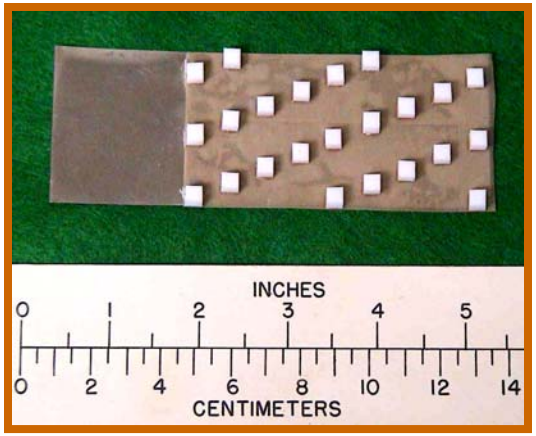
5-cm Wind Tunnel Internal Components

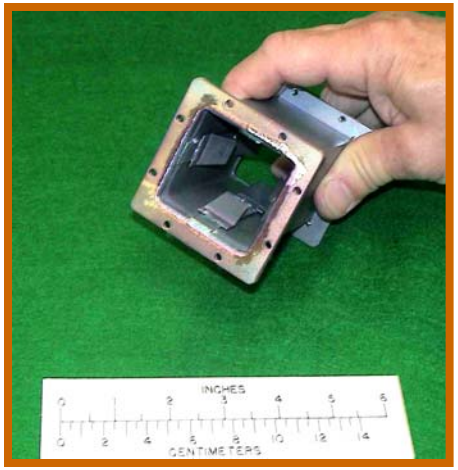


Turbulence Strakes and Roughening Blocks

Adjustable Test Section Piston



Roughening Blocks Only



Static Mixer

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5-cm Wind Tunnel Sections

- **Transition from Environmental Control Unit (Miller Nelson) (1.0-cm diameter) to 5x5-cm wind tunnel**
- **Turning Vane**
  - 90° flow turn
- **Fetch**
  - Smooth
- **Test Section**
- **Static Mixer**
- **Sampling Section**
- **Blower**

Chemical Resistant Coating

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5-cm Wind Tunnel Instrumentation

- **Hotwire anemometer – Velocity near drop**
- **Temperature – Test Section**
- **Static Pressure – Test Section**
- **Humidity – Upstream of Test Section**
- **Chemical Vapor Sampling – Downstream of Test Section**

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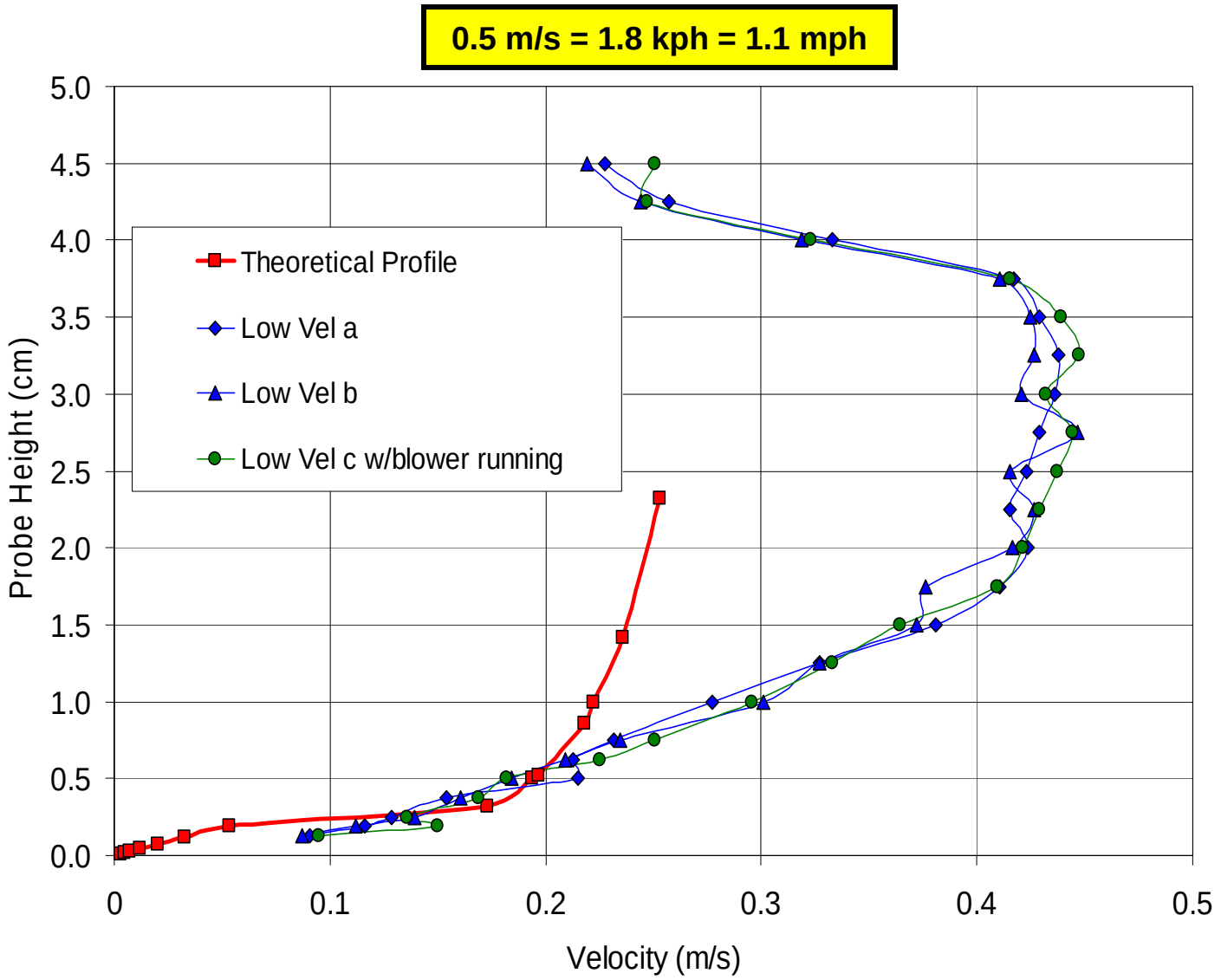
Low Velocity Comparison

(Q=38 Lpm, T=30 °C, RH=50%, roughening blocks only)



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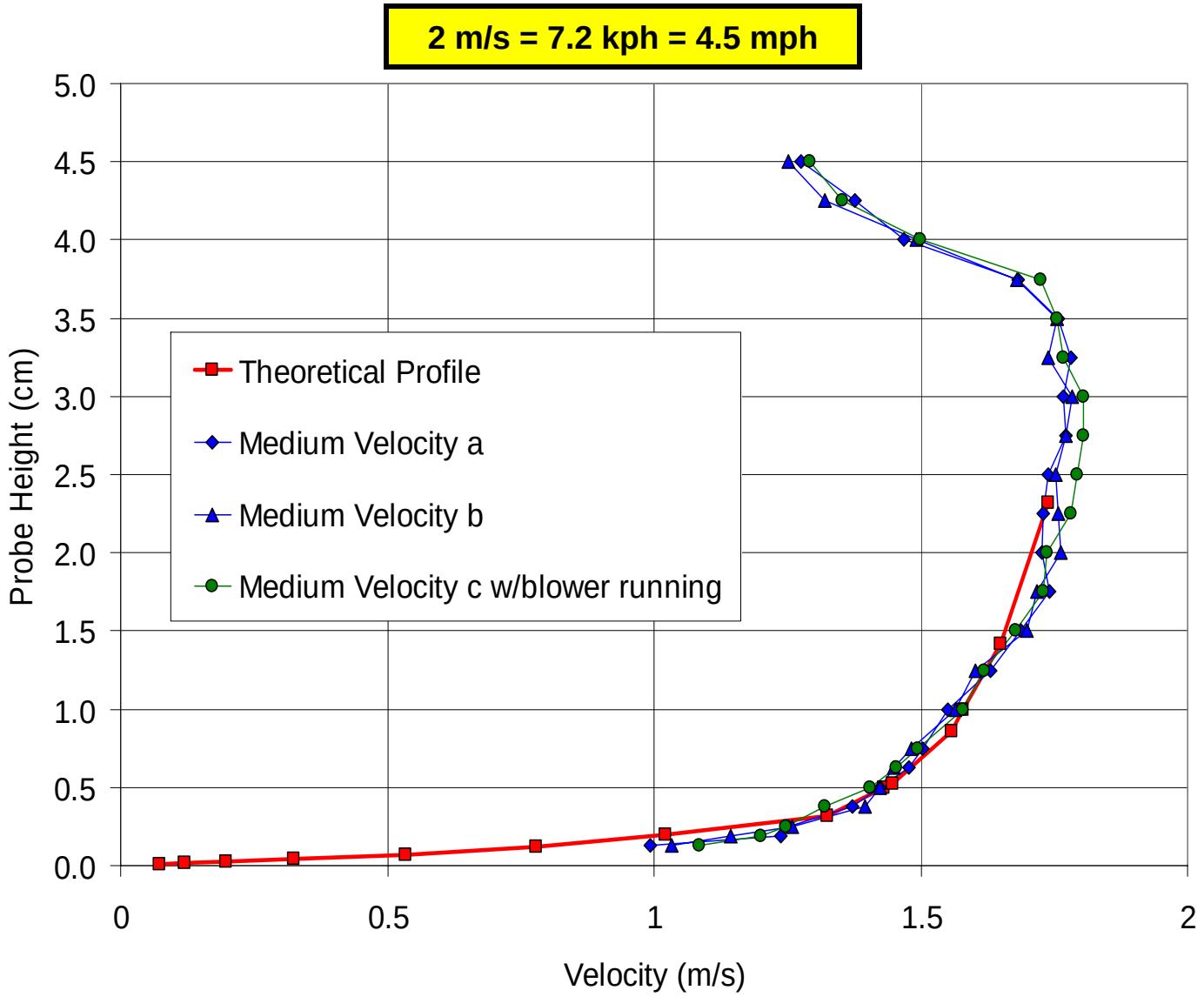
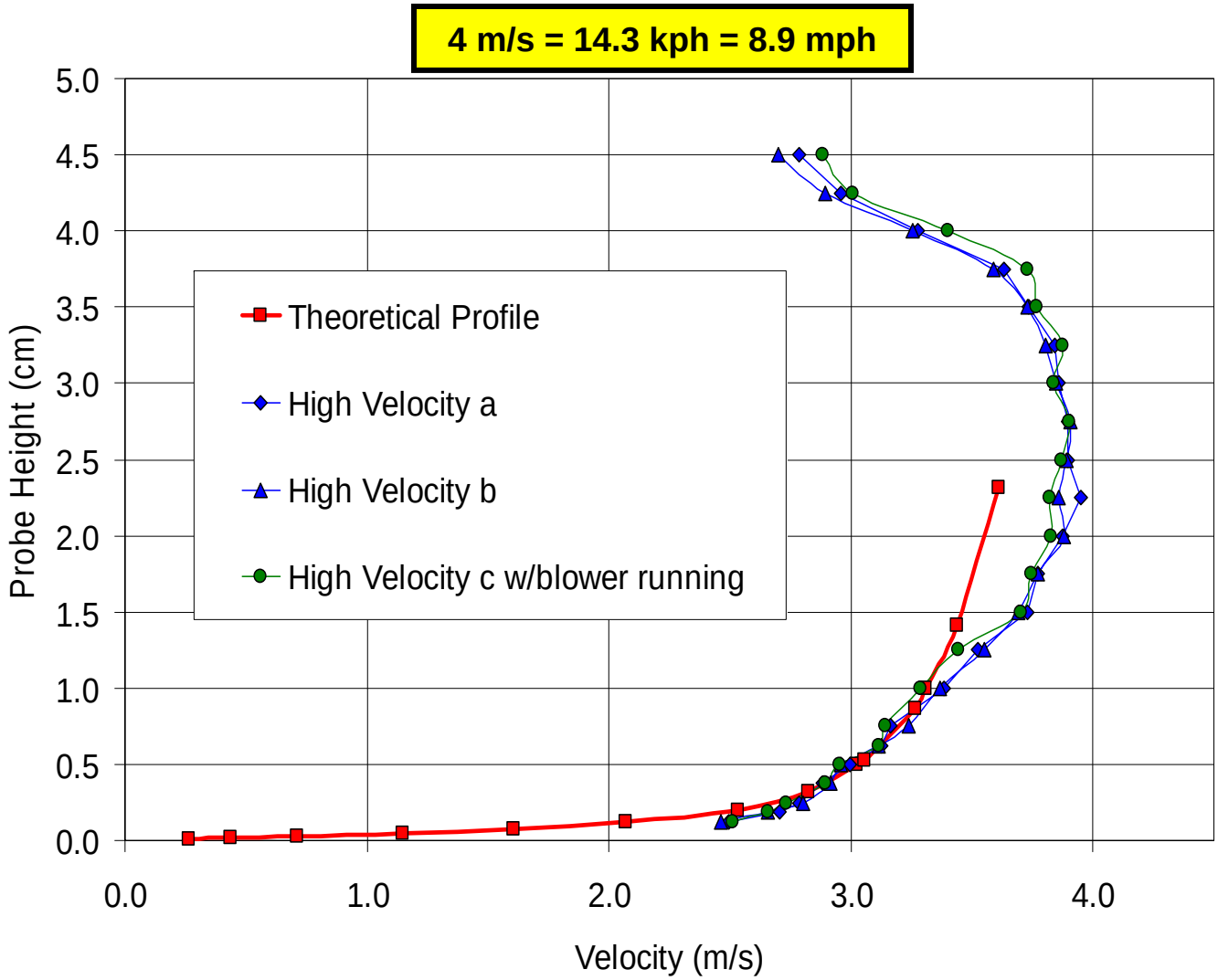
Medium Velocity Comparison

(Q=185 Lpm, T=35 °C, RH=50%, roughening blocks only)



High Velocity Comparison

(Q=415 Lpm, T=35 °C, RH=50%, roughening blocks only)



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Summary - Theoretical vs. Experimental Velocity Profiles

- **5-cm Wind Tunnel and 2950 Microbalance Wind Tunnel**
  - Low Velocity: fair agreement from 0.5 cm to surface.
  - Medium Velocity: excellent agreement from tunnel centerline to surface.
  - High Velocity: excellent agreement from 1-cm to surface.
- **Q600 Microbalance Wind Tunnel**
  - CFD runs completed and velocity profiles are being measured

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Target Defeat Team Facilities

Wind Tunnels

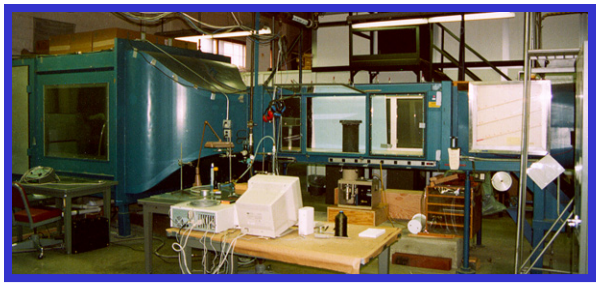
- Subsonic Wind Tunnel
  - Aerosol generation capabilities to test Bio Detection systems
- Subsonic Vertical Wind Tunnel
- Transonic Wind Tunnel
- Supersonic Wind Tunnel
- Breeze Tunnel

Compressed Gas Guns

- 25mm diameter, general purpose
- 76mm diameter spinning barrel
- 155mm diameter spinning barrel
- Gator gun for ground impact studies

Other Facilities

- Laboratory Test Fixture for Non-Rigid Payloads Flight Simulator
- Aerosol/Smoke Chamber



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